Radiance Trending Using PDFs of AIRS with Comparisons to ERA Re-Analysis

L. Larrabee Strow, Sergio De-Souza Machado,
Howard Motteler, Andy Tangborn, and Chris Hepplewhite

Department of Physics, JCET
University of Maryland Baltimore County (UMBC)

CLARREO Science Team Meeting
January 2014
Greenbelt, MD

Overview

- What can we learn from long-wave operational sounder hyperspectral record?
- Create uniform radiance record: AIRS, IASI, CrIS
- Instrument stability (AIRS)
- Connecting AIRS with CrIS
- Enhance detection capability, lower accuracy requirements with PDF-based approach
- Comparison of AIRS 10-year record with ERA re-analysis using UMBC's SARTA RTA for radiances simulation

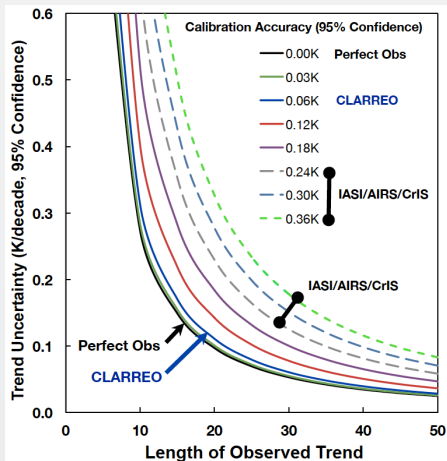# Framework for Radiance Climate Data Record
Using AIRS, IASI, CrIS
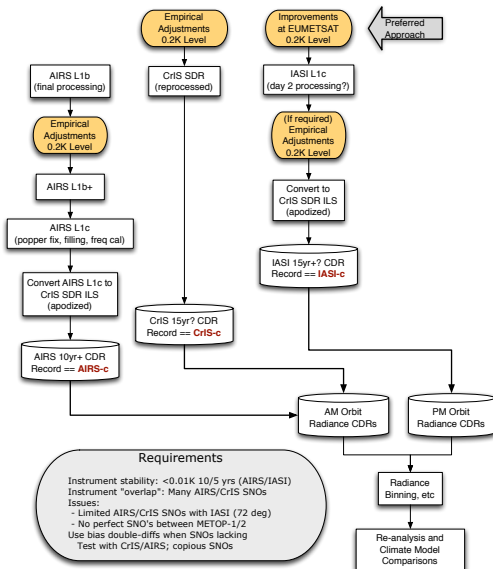
AIRS-c, IASI-c, CrIS-c are individual instrument products converted to a common spectral response (SRF).

Requires:

- Instrument stability (CrIS?)
- Instrument overlap (AIRS/CrIS with IASI?)
- SRF conversion algorithms
- Hopefully, B(T) differences dominated by on-board blackbody differences
- Cooperation among instrument teams, and ???

Flowchart text:

Empirical Adjustments 0.2K Level

Improvements at EUMETSAT 0.2K Level

Preferred Approach

AIRS L1b (final processing)

CrIS SDR (reprocessed)

IASI L1c (day 2 processing?)

Empirical Adjustments 0.2K Level

(If required) Empirical Adjustments 0.2K Level

AIRS L1b+

AIRS L1c (popper fix, filling, freq cal)

Convert to CrIS SDR ILS (apodized)

Convert AIRS L1c to CrIS SDR ILS (apodized)

IASI 15yr+? CDR Record == **IASI-c**

CrIS 15yr? CDR Record == **CrIS-c**

AIRS 10yr+ CDR Record == **AIRS-c**

AM Orbit Radiance CDRs

PM Orbit Radiance CDRs

Requirements

Instrument stability: <0.01K 10/5 yrs (AIRS/IASI)
Instrument "overlap": Many AIRS/CrIS SNOs
Issues:
- Limited AIRS/CrIS SNOs with IASI (72 deg)
- No perfect SNO's between METOP-1/2
Use bias double-diffs when SNOs lacking
Test with CrIS/AIRS; copious SNOs

Radiance Binning, etc

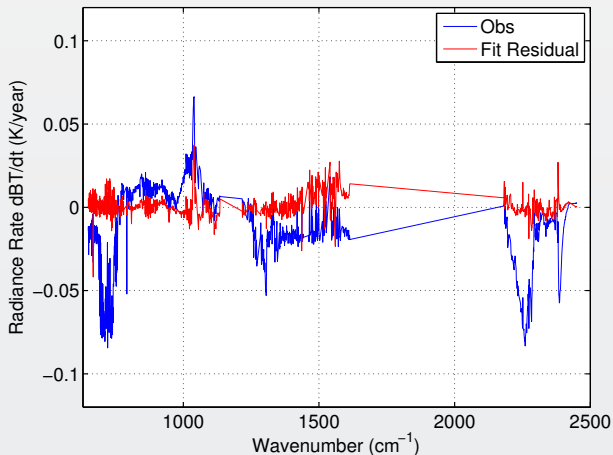Re-analysis and Climate Model Comparisons

3

CLARREO LongWave Requirements

- Can we lower AIRS/CrIS effective calibration accuracy? Yes?
- Is the Trend Uncertainty (mean radiance change) the proper metric? Use PDF/quantile analysis to enhance detection.
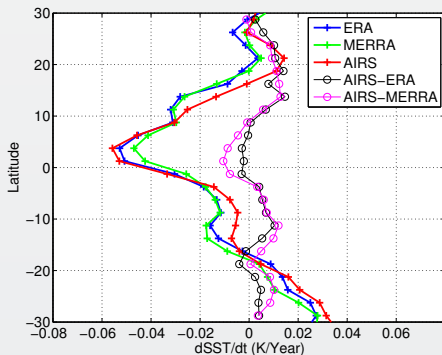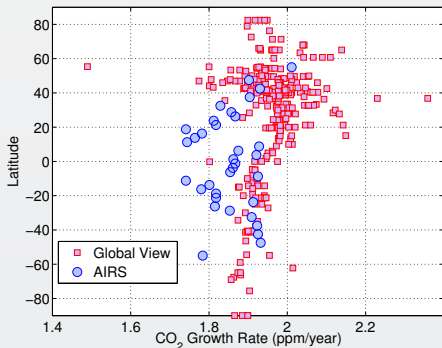
Overview
○○○

AIRS Stability
●○○○

AIRS vs CrIS
○○

PDF/Quantiles
○○

Cloudy RTA
○○○○○

Time Series: ERA vs AIRS
○○

Quantile Obs
○○○○○○○○○

AIRS Stability: Clear Subset Radiance Rate Fits

10-Year linear rates
Not frequency corrected, no L1c

OEM Fit Results
All a priori = 0, covariance = ~3X nominal variability

AIRS SST - SST CDR: +0.004 ± 0.006 K

AIRS CO_2 - In-Situ CO_2: -0.004 ± 0.004K

Overview ○○○
AIRS Stability ○○●○
AIRS vs CrIS ○○
PDF/Quantiles ○○
Cloudy RTA ○○○○○
Time Series: ERA vs AIRS ○○
Quantile Obs ○○○○○○○○○

OEM Profile Fits, N. Mid Lats: Reasonable Agreement

AIRS: Blue, MERRA: Green, ERA: Red, ERA: All Scene is Black
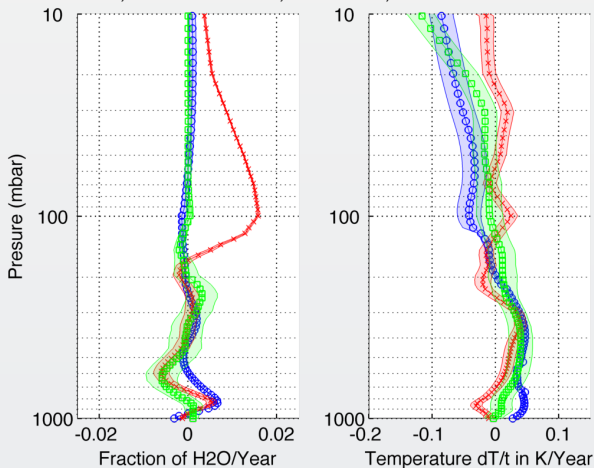
Blue is OEM retrieval. Green, blue are linear rates derived directly
from MERRA, ERA model fields matched to AIRS clear observations.

Overview
○○○

AIRS Stability
○○○●

AIRS vs CrIS
○○

PDF/Quantiles
○○

Cloudy RTA
○○○○○

Time Series: ERA vs AIRS
○○

Quantile Obs
○○○○○○○○○

OEM Profile Fits
All-Scene ERA Result Shown

AIRS: Blue, MERRA: Green, ERA: Red, ERA: All Scene is Black
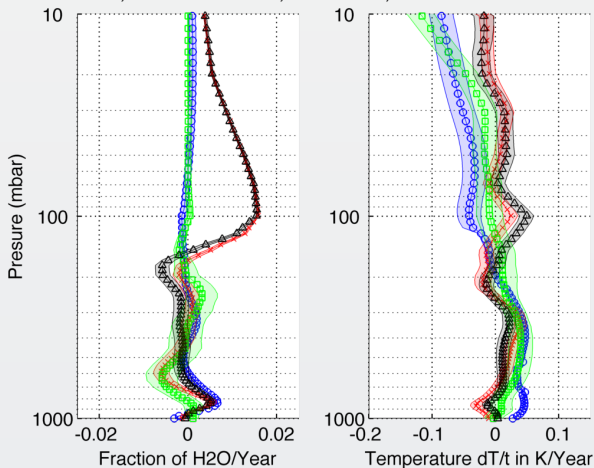
Black is ERA using all model fields, not just those co-located to AIRS clear subset.

Connect AIRS to CrIS: SNO Comparisons at 900 cm^{-1}
Ensure agreement versus scene temperature
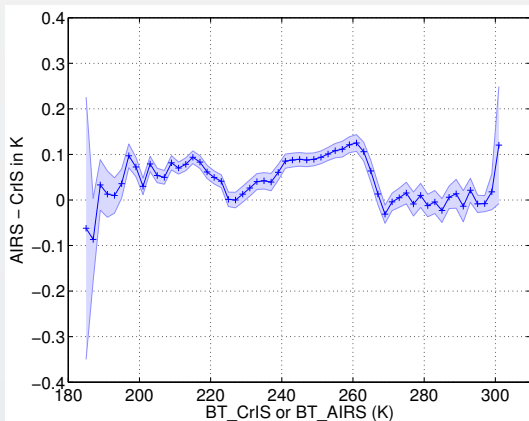
More work needed (Univ. Wisc. SSEC has an extensive effort). For
CLARREO, relevant number is difference if uncorrected, is
standard deviation *if* well-defined offsets can be derived.

H. Motteler: AIRS –> CrIS ILS Conversion
Robust approach uses AIRS Measured ILS functions.

Convert AIRS ILS to CrIS for long-term radiance record.
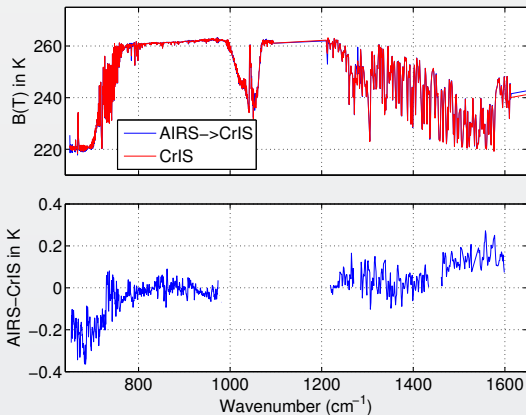
This comparisons shows SNO intercomparisons for 1 day, Oct. 1, 2012. A key part of this work is JPL AIRS Project L1c product, removing effects of popping channels.

Overview
○○○

AIRS Stability
○○○○

AIRS vs CrIS
○○

PDF/Quantiles
●○

Cloudy RTA
○○○○○

Time Series: ERA vs AIRS
○○

Quantile Obs
○○○○○○○○○

PDF Measurement Approach
Do not average all-sky radiances.
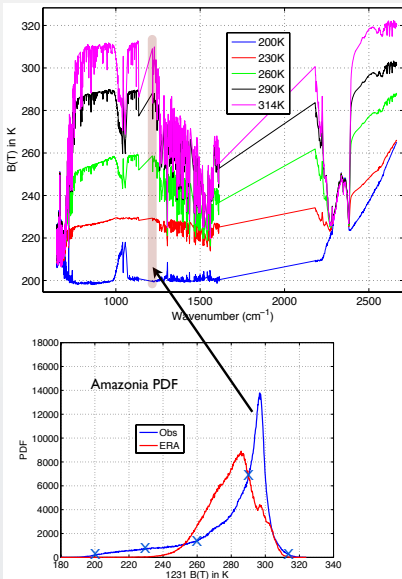
Retain more information: PDF rates, not Radiance Rates

- Averaging clear with cloudy scenes destroys information
- Bin (create PDFs) versus variable related to cloudiness
- I used 1231 cm^{-1} channel B(T): clearest window channel
- Data Set: 10 years of AIRS, only FOVs on each side of nadir
- Bins of B(T) 1231 cm^{-1}, from 190:1:320K
- Mean BT spectra in each bin are stable versus time
- All the information is in the PDFs in each bin

Diurnal Variability of PDF Rates (5-year rates)

PDFs divided by 25; Mean BT Rates (AIRS) -0.03K, -0.08K (IASI) 0.01K, 0.01K, all $2\sigma \sim 0.15$K
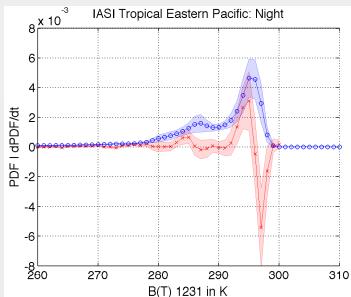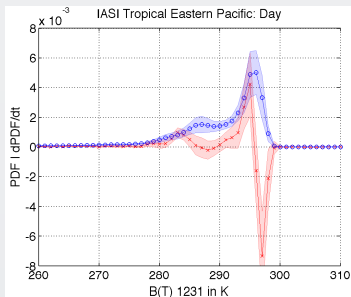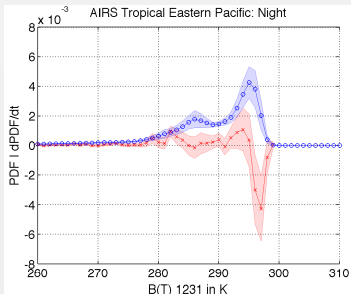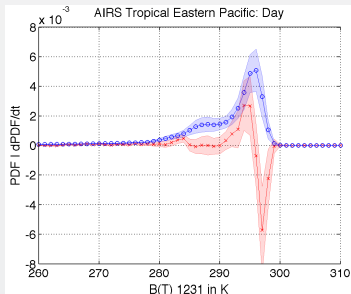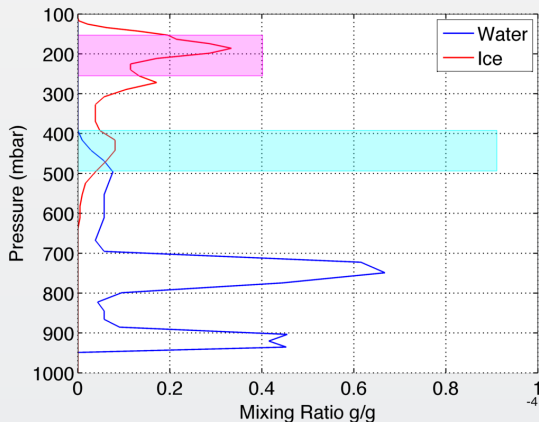
Comparisons to ERA Re-Analysis
Re-Analysis heavily used by climate community

- CLARREO: compare model to observations in radiance space
- SARTA is UMBC RTA, used for AIRS and by NOAA
- Developed mapping of model clouds fields to RTA, 2 scattering layers only for now
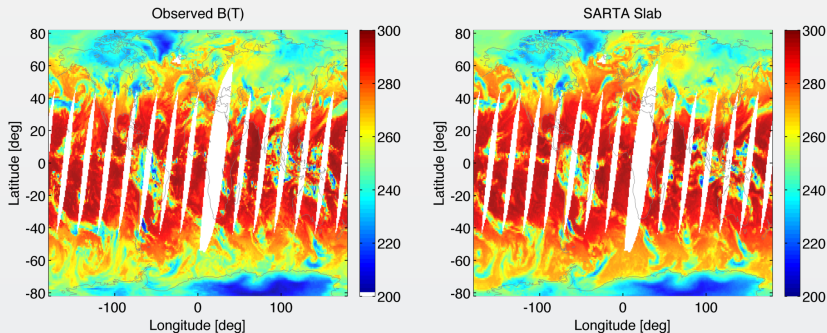- Comparisons to 100-layer cloud overlap models are quite good!

SARTA: 2-cloud layer RTA

100-layer cloud RTA too slow for our purposes. Convert re-analysis cloud fields into two layers (water, ice). Top of cloud where optical depth is near unity. Results very similar to PCRTM (and SARTA 100-layer), far closer than differences to observations.
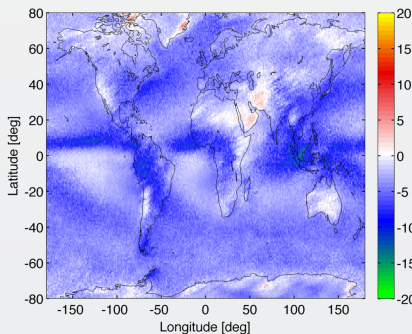
Overview
○○○

AIRS Stability
○○○○

AIRS vs CrIS
○○

PDF/Quantiles
○○

Cloudy RTA
○○●○○

Time Series: ERA vs AIRS
○○

Quantile Obs
○○○○○○○○○○

Overview of SARTA vs Observations: ECMWF, not ERA
March 11, 2012, 1231 cm^{-1} channel
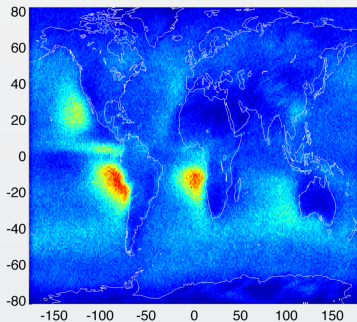

Comparisons quite good at this scale.

SARTA Comparisons to Observations
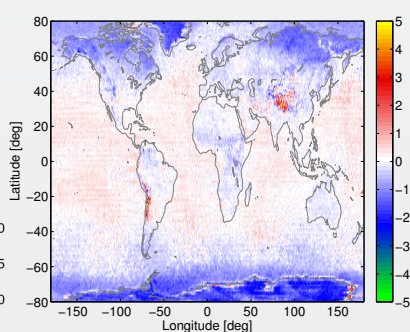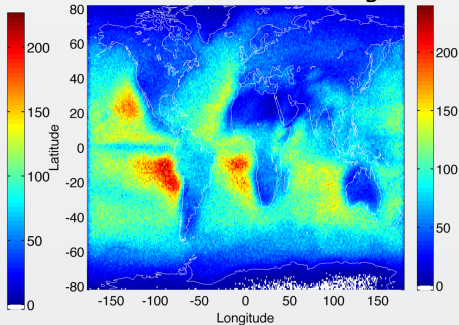

High cloud scenes removed for 1441 cm^{-1} bias analysis.

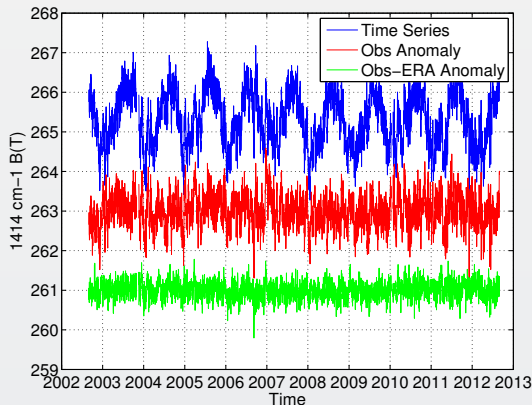# Marine Boundary Layer Cloud: Obs vs ERA

Obs: 6-12K Forcing

Calc: 2-7 Forcing

ERA MBL clouds too low. SARTA 2-slab and PCRTM agree, not an
issue with 2-slab geometry.

500 mbar Global Water Channel Time Series
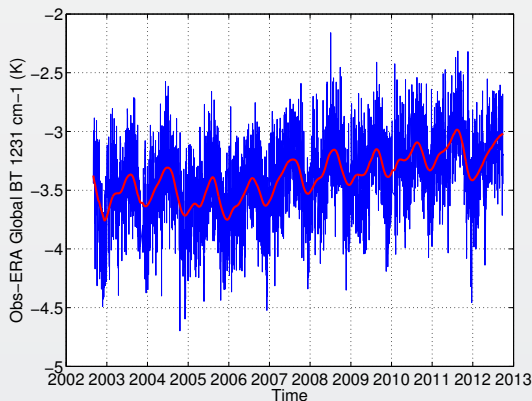$1414\ cm^{-1}$, No PDF/quantile binning

Global: ERA captures global variability.
Obs: -0.016 ± 0.01 K/year
ERA: -0.014 ± 0.009 K/year

1231 cm^{-1},Global Window Channel Time Series
Simple subtraction of Obs-Calc, daily global binning

Red curve is smoothing. Clear long-term differences.

Quantile vs PDF Approach

- Previous approach: B(T) 1231 cm^{-1} is independent binning variable: find PDFs of B(T) 1231 since closely correlated with clouds.
- New approach: Make cumulative probability distribution independent variable: find mean value of B(T) 1231 in each "quantile" bin.
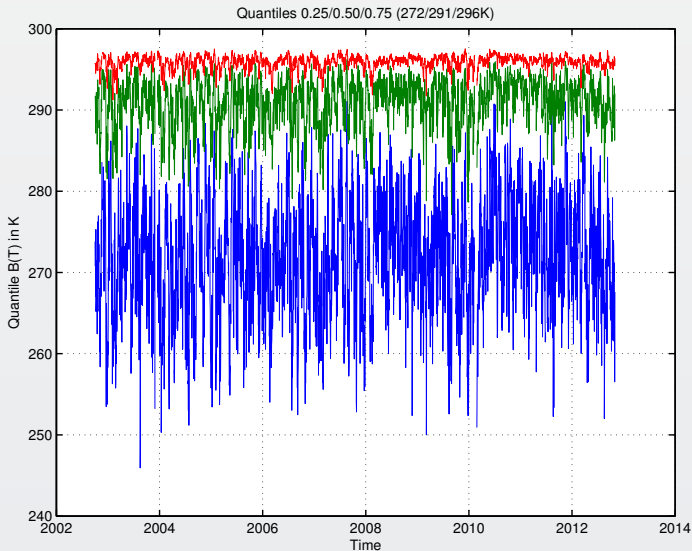- Leads to easier interpetation

Quantiles (cumulative probability distribution): 0:dp:1. Sort B(T) in ascending order and fill bins.

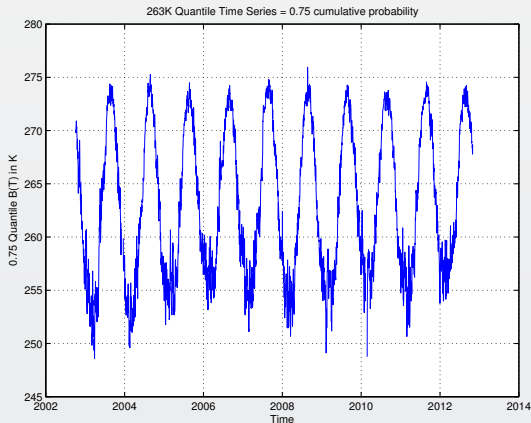Usually plot B(T) that goes with each dp bin, rather the cumulative probability.

Tropical Western Pacific
Three quantile time series: 0.25, 0.50, 0.75

Quantiles 0.25/0.50/0.75 (272/291/296K)

Arctic
0.75 probability bin

263K Quantile Time Series = 0.75 cumulative probability

Approach very useful for studying extremes. Note warmer winter radiances.

Quantile Rates

- Subset of some geographic region (TCON regions)
- Determine quantiles for each day in 10-year period
- Fit time series of quantiles for linear growth rate (remove seasonal signals).
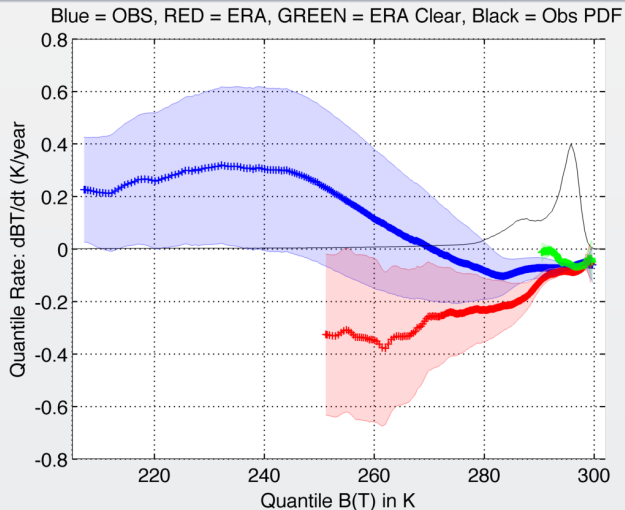- Examine variability versus models (ERA)

Tropical Western Pacific

Blue = OBS, RED = ERA, Black = Obs PDF
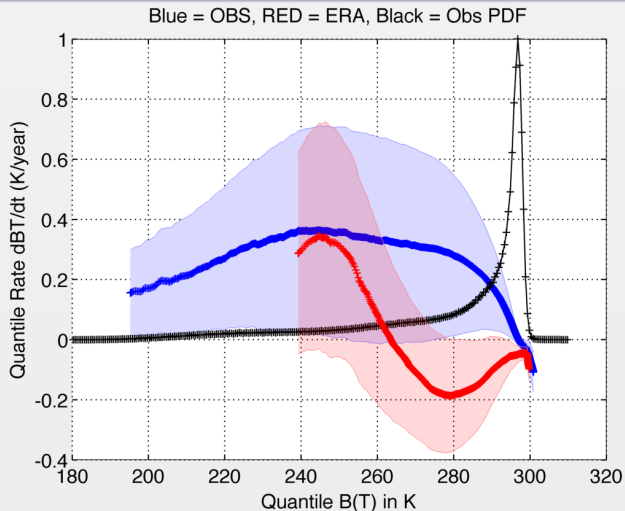
Mean rate: 0.14K ± 0.04K
However, quantile analysis shows cooling near high-end sensitive to surface.
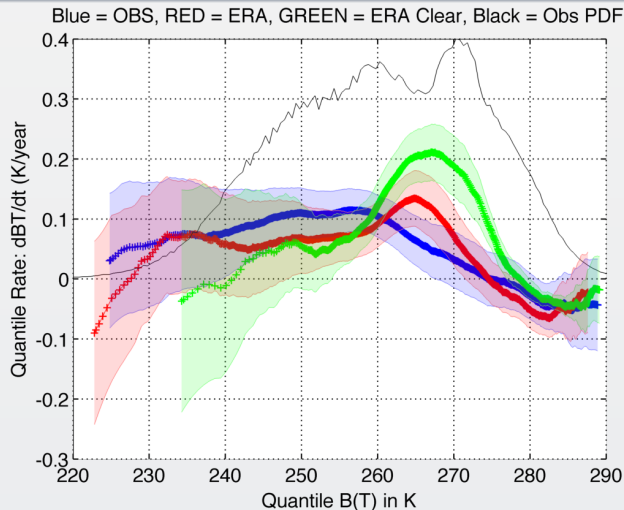Model shows more clouds compared to observations, but error bars overlap.

Tropical Eastern Pacific

Blue = OBS, RED = ERA, GREEN = ERA Clear, Black = Obs PDF

Mean rate: -0.04K ± 0.02K
Model may have fewer marine-boundary layer clouds over time, but error bars overlap.
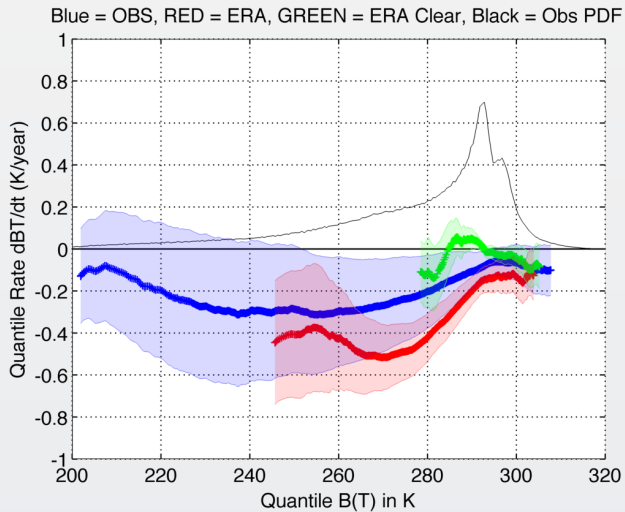
Arctic

Blue = OBS, RED = ERA, GREEN = ERA Clear, Black = Obs PDF

Mean rate: $0.12K \pm 0.01K$

As per Artic time series, warmer winters, slightly cooler for warm observations.

Amazonia

Blue = OBS, RED = ERA, GREEN = ERA Clear, Black = Obs PDF

Mean rate: -0.09K $\pm$ 0.05K
Good agreement with ERA, lower cloud forcing

Conclusions

- Operational sounders should be able to contribute to CLARREO-like observations
- However, many details need careful attention and peer review, and:
- Different groups need to cooperate!
- A PDF/quantile approach increases information content retrieval compared to mean spectra
- Eventually need to move from analysis of single channels, to retrievals of cloudy spectra